PATENT
TH-1258 (US)
ERM:SWT

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re application of Donald W. Allen et al Serial No. 09/625,893 Filed: July 26, 2000 SMOOTH SLEEVES FOR DRAG AND VIV REDUCTION OF CYLINDRICAL STRUCTURES	Group Art Unit: 3673 Examiner: K. Mitchell January 20, 2005

DECLARATION OF DR. DONALD W. ALLEN

I, Dr. Donald Wayne Allen declare as follows:

1. My name is Dr. Donald Wayne Allen. I am presently the Business Team Manager of the Pipelines Business Group for Shell Global Solutions (U.S.) and named inventor on the above-referenced patent application. I am more than 18 years of age, have not been convicted of a felony or a crime of moral turpitude, am of sound mind, and am competent to make this Declaration.

2. I received a B. S. in Mechanical Engineering from Texas A&M University in 1981, and a Ph. D. in Mechanical Engineering from Rice University in 1986. I have been a Staff Research Engineer – Offshore Structures for Shell since August 1986. I consult with various Shell and non-Shell entities regard the potential vortex-induced vibration ("VIV") problems with various subsea structures. In this role, I have performed VIV analyses of offshore and subsea structures such as production platforms, risers, riser bases, jumpers, tendons, spars, and pipeline spans.

3. I have performed research directed to the characterization of VIV conditions. I have also performed research directed to the development of VIV suppression devices, including various helical strake systems, fairing systems and shroud or covering systems. This research includes work performed at various Shell facilities located in Houston, Texas and at the Naval Surface Warfare Center, located in Caderock, Maryland.

4. I have authored and published a number of papers on the subject of VIV and its suppression, including a paper I co-authored with Dean Henning, entitled *Vortex-Induced Vibration Tests of a Flexible Smooth Cylinder at Supercritical Reynolds Numbers*, May 1997, (the "Allen Paper"). I have also previously filed a Declaration in support of the present application, signed August 22, 2002 ("Allen Declaration 1").

5. I have reviewed the Office Action that was issued in the above-referenced application, in which the Examiner comments that the statements made in Declaration are accepted at face value. However, the Examiner questions why the same structure that is specifically noted as not reducing/controlling drag and VIV can be used to successfully reduce/control drag and VIV. It is stated that there is either an enabling step or a feature missing or the claimed invention will not work.

6. I have reviewed Declaration I and the Allen Paper and believe the statements made therein to be consistent. The reasons focus on the samples themselves. With reference to the Allen Paper, the cylinders used in the paper were 78.5" in length. The ABS cylinder had an outside diameter of 3.5 in. and the PVC cylinder had an outside diameter of 5.5625 in. P. 681, col. 1, Test Setup. As may be readily determined, this resulted in cylinder surface areas of approximately 863.2 in^2 and 1371.8 in^2, respectively.

7. The data presented in the Allen Paper details the PVC pipe as having an average k/D surface roughness of 9.94E-4, with samples in the ranging from 8.86E-5 to 1.09E-4 and the ABS cylinder having an average cylinder roughness k/D of 1.37E-4, with the samples ranging from 1.21E-4 to 1.51E-4. While the Allen Paper discusses cylinders having the above ranges, it is now clear to me that one could misconstrue the paper as indicating that there existed multiple pipes of each type. The tests were carried out with a single pipe of each type, with the surface roughness information being obtained from various samples from that single test pipe. While the following discussion focuses on the testing of the PVC cylinder, identical test methods were used to determine the roughness for the ABS pipe.

8. The methodology used to determine the surface roughness is as follows: Five 1 inch by 1 inch samples were cut from each pipe following the flow tests. The sites for the samples were arbitrarily selected. The approximately 1 in^2, was selected to permit a sample to be mounted on a microscope slide. The microscope then sampled 2mm x 2mm (0.0062 in^2) out of the 1 square inch. The total area sampled (0.031 in^2 5 multiplied by 0.0062 in^2) for the surface roughness test represents 0.00226 percent of the total surface area of the PVC pipe. The confocal scan of each sample using a laser microscope was performed at Shell's facilities at the Westhollow Technology Center.

9. The results of the 1995 tests for the PVC pipe are summarized below in Table 1.

Sample	R_a (μm)	R_a (in.)	R_q (μm)	R_q (in.)	k/D
1	14.42	5.58E-04	18.41	7.25E-04	1.02E-04
2	13.91	5.48E-04	17.97	7.07E-04	9.85E-05
3	12.52	4.93E-04	15.97	6.29E-04	8.86E-05
4	15.42	6.07E-04	19.57	7.70E-04	1.09E-04
5	13.94	5.49E-04	17.88	7.04E-04	9.87E-05
Mean	14.04	5.53E-04	17.96	7.07E-04	9.94E-05

Table 1

In Table 1, R_a is the integrated average peak to trough roughness, and R_q represents the scatter of roughness about the mean roughness. An Appendix is attached to this declaration setting forth the formulas for determining these parameters. As may be

seen from Table 1, and the explanation within the Appendix, smoothness can vary significantly from sample to sample, as well as within a sample.

10. It is this variation, both within a sample and as from sample to sample, together with the relatively small sampling area, that leads me to believe, in retrospect, that the samples were not fully representative of the overall smoothness characteristics of the tested cylinders.

11. In 1997, Shell's VIV group undertook a second set of tests associated with drilling and production riser smoothness and VIV response. These tests were carried out at the Rotating Arm Facility of the U.S. Naval Surface Warfare Center. These tests were designed to characterize the smoothness of cylindrical bodies and VIV response. This set of tests differed in a number of ways.

12. The tests were carried out utilizing one smooth fiberglass pipe and three non-smooth fiberglass pipes. The smooth pipe was 2.5 in. fiberglass pipe, 211.5 in. in length. The fiberglass pipe was a mandrel wound pipe with a diameter slightly greater than 2.5 inches. The pipe was then surface ground to achieve the desired diameter and smoothness. Multiple smooth cylinders were prepared in a like manner but only one smooth cylinder was used in the tests. The remainder of the smooth cylinders were held as replacements in the event one or more of the smooth cylinders were damaged or destroyed during testing. The three non-smooth cylinders did not have the grinding process applied to them but were also 2.5 in. in diameter. Rough cylinder #1, as referred to in the above-captioned application was also 211.5 in. in length. Rough cylinders #2 and #3 were each 207.5 in. in length.

13. The fiber angles and layer thicknesses of the primary test cylinders were chosen so that the pipe joints had an apparent axial modulus of about 2.2x106 psi in tension and an apparent axial modulus of about 2.0x106 psi in bending. The modulus calculations are based upon an assumed glass fiber volume content of 52 percent. The pipe was manufactured by filament winding E-glass rovings impregnated in an epoxy vinyl ester resin over a 2 in. (outside diameter.) steel mandrel. The product had a 20 mil Cveil liner followed by a "wet" winding of the E-glass rovings to a minimum diameter of 2.50 in. All samples were filament wound at multiple angles, 45/25/25/45. All products were left un-pigmented. No external corrosion barrier was applied since many of the pipes were later surface ground to the desired surface finish.

14. The Rotating Arm facility differs from the equipment utilized in the Allen Paper. In the 1997 tests, the pipe was placed within the rotating arm frame, lowered into the tank and rotated in a manner similar to a watch hand to create flow across the pipe. It will be appreciated that the flow velocity across the pipe was greater at the outer portions of the pipe than the inner portions, thereby creating sheared flow. Two accelerometers were placed on each pipe at a position 1/6 of each pipe length in from the respective ends. The pipes were located at selected speeds, with the accelerometers measuring the VIV response. The Reynolds number is a dimensionless parameter defined as:

$$R_e = \frac{\rho U l}{\mu} = \frac{U l}{\nu}$$

where ρ is the fluid density, μ is the viscosity coefficient, ν is the kinematic viscosity coefficient (ρ/μ), U is the characteristic velocity of the fluid and l is a length parameter, such as the diameter of a pipe or diameter or length of a body, in the case of flow external to a body. Thus, by varying the speed of rotation, different Reynolds numbers were obtained for each pipe.

15. The pipes were placed in the tank, rotated and data collected. The VIV response of the pipe was set forth in Figures 15 and 16 of the above-captioned application. After the tests, five samples were cut from the pipes at arbitrary spaces. As with the 1995 tests, the samples were 1 inch by 1 inch with 2mm x 2mm (0.0062 in^2 sample areas used by the confocal laser microscope at Shell's Westhollow facility. The average smoothness for the pipes is set forth in Table 2:

Cylinder	R_a microns	R_a inches	k/D
Smooth Cylinder	3.23	1.272E-4	5.088E-5
Rough Cylinder #1	4.925	1.939E-4	7.756E-5
Rough Cylinder #2	63.2	2.493E-3	9.972E-4
Rough Cylinder #3	147.8	5.82E-3	2.328E-3

Table 2

In an effort to confirm R_a, a profilometer test was run on a one inch long sample cut from the smooth cylinder. At least two profilometer measurements were made on the sample, resulting in an average smoothness (R_a) of 3.65 microns or 1.437E-4 inches. Based on this confirmation, the confocal data for the smooth cylinder was believed to be correct.

16. The 1995 tests, as reported in the Allen Paper, and the 1997 tests that are part of the present application resulted in different outcomes. The 1997 tests clearly demonstrated that a body having the claimed k/D ratio in the exhibited range of Reynolds numbers saw a dramatic reduction in VIV. I believe that it could be attributable to one or more factors.

17. The first possibility deals with surface preparation. The smooth cylinder used in the 1997 tests was known to have an initial high degree of surface irregularities that required grinding of the cylinder. This grinding process most probably resulted in a more uniform surface smoothness (as well as a lower surface roughness). In contrast, the ABS and PVC cylinders used in the 1995 tests were purchased commercially and were selected for their lack of visual surface irregularities. The 1995 cylinders were then wiped with acetone to achieve the exhibited smoothness. (See Allen Declaration 1, paragraph 11). This is borne out by the comparisons between the R_a and k/D values for the 1995 and 1997 tests. Therefore, since the 1997 smooth pipe had a more uniform surface roughness, then the roughness samples are more representative, and accurate, than the samples for the 1995 tests. I believe that the uniform smoothness of the fiberglass cylinders is the primary reason that the 1997 tests demonstrated improved VIV and drag performance.

18. The smooth cylinders used in the 1997 tests were filament wound and surface ground. This resulted in the uniform smoothness and an extremely low ovality (i.e. they were very close to circular in cross section). The smooth cylinders used in the 1995 tests

most likely had greater ovality than the 1997 smooth cylinder, due to the extrusion process used to make them and their handling prior to testing (they were bought off the shelf and not custom made for the tests). A higher and varying ovality across the length of the cylinder could have resulted in varying shear flow, which could have increased the vibration characteristics of the ABS and PVC cylinders.

19. Further, the nature of the materials themselves could have contributed to the differences. The PVC and ABS cylinders used in the 1995 tests had a modulus of elasticity of 457 ksi and 220 ksi, respectively. The wound fiberglass cylinder had a modulus of elasticity of 2,000 ksi. Thus, the fiberglass cylinder cross section would be less likely to deform as a result of flow than the PVC and ABS cylinders. This potential change in cross section could have resulted in further increased ovality.

20. Given that the samples from the PVC and ABS cylinders fall within the claimed k/D range, the only logical conclusion that can be drawn from their lack of VIV and suppression is that the PVC and ABS samples were not representative of the overall smoothness of the cylinders. This factor, together with variances in the ovality and material characteristics resulted in poor VIV performance. The preparation of the smooth fiberglass cylinder used in the present invention resulted in a more uniform surface leading to VIV and drag suppression.

I am aware that willful false statements and the like are punishable by fine or imprisonment, or both under Title 18 U.S.C. §1001 and may jeopardize the validity of the application or any patent issuing hereon. All statements made herein are made based on my own knowledge are true and that all statements made on information and belief are believed to be true.

Donald W. Allen, Ph.D.

Donald W. Allen

Date: 1-20-05

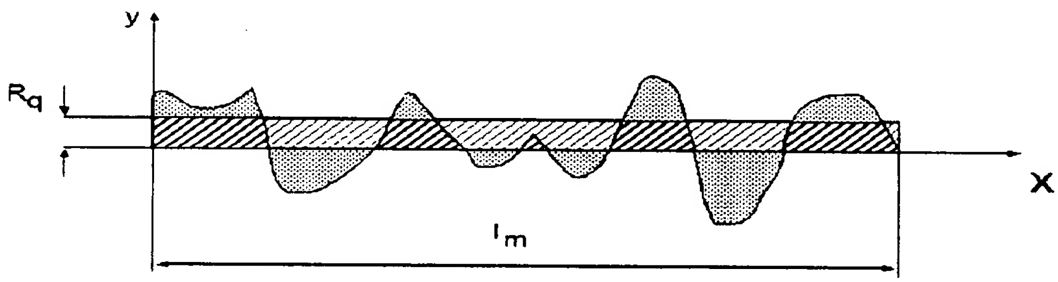
APPENDIX

Definitions of R_a, R_q

Surface, Rq value

This number represents the scatter of the amplitude values around the zero line.
This value is calculated using the following formula:

$$R_q = \sqrt{\frac{1}{l_m}\int_0^{l_m} y^2(x)\,dx}$$

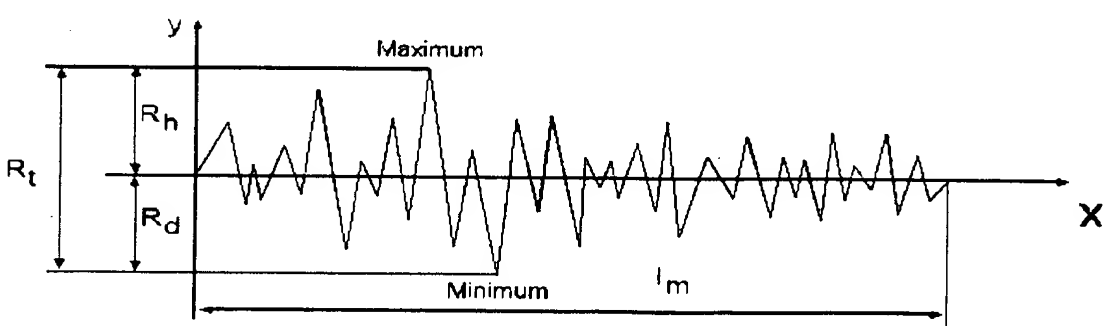


Surface, Rt, Rh, Rd values

These numbers represent the difference between maximum and minimum of a profile (span).

The values are calculated using the following formulae:

$$R_h = Maximum(y_i)$$
$$R_d = Minimum(y_i)$$
$$R_t = R_h - R_d$$



Surface, Ra value

This number represents the average peak-to-trough height of a measuring surface.
The average peak-to-trough height corresponds to the height of a rectangle the length of which is equal to the total measuring distance ***lm***
The surface area of the rectangle must be equal to the sum of the area enclosed between roughness profile and centerline.
The average peak-to-trough height is calculated using the following formula:

$$R_a = \frac{1}{l_m} \int_{x=0}^{x=l_m} |y| dx$$